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AUTHOR Masturzi, Elio R.
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ABSTRACT

EX.MAIN, a model for maintenance and staff training which combines knowledge based expert systems and computer based training, was developed jointly by the Department of Production Engineering of the University of Naples and CIRCUMVESUVIANA, the largest private railroad in Italy. It is a global model in the maintenance field which contains both operative and training features, with the knowledge based expert system component giving the model its operative expert procedure, while the computer based training model provides the training component. The latter component, based on multimedia concepts, gives staff the required information by means of a text and graphic video pages together with live images of railroad braking system components displayed on a television monitor. Four figures illustrate the model and the make-up of the working team which developed it. (5 references) (EW)

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EX.MAIN

Expert System Model for maintenance and staff training

Elio Masturzi

This paper refers to a research project in the area of the applications of the Expert Systems and Computer Based Training for the solution of maintenance problems.
The participants in this project were:

- College of Manufacturing, Cranfield Institute of Technology (U.K.)
- Department of Production Engineering, University of Naples (I)
- Circumvesuviana Railway Company, Naples (I)
- Technova Company, Naples (I)

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1) INTRODUCTION

For many years, men have foreseen the incorporation of human-like intelligence into a machine that is constituted by hardware which is more or less complex, but inanimate.

Thus, this type of intelligence has been considered as being artificial.

The field of "Artificial Intelligence" (AI) appears to be very exciting for researchers and technicians as well as being extremely useful to many industries, in particular the computer industry.

The application of AI in a very large number of sectors (management, manufacturing, government, commercial, health care, etc.) discloses a new and exciting business horizon for the industry.

The science of AI has made great strides from the day of the historical conference in Dartmouth College (1956). During that conference, John McCarthy first introduced the term " Artificial Intelligence" attributing it with the same meaning as we do today .

Currently, the science of AI breaks down into three basic branches :

- Robotics,
- Natural Languages,
- Expert Systems.

The Robotics branch includes machines designed and produced to "see" and "feel" their environments, so that they are able to respond to the changes in their environment and can perform a set of pre-defined operations.

The second branch of AI deals with the development of systems (hardware and software) which can understand the language used by people in everyday conversation in it's common forms (texts, speaking, images, etc.). The set of information collected in these ways is analyzed to identify individual words and eventually to combine the basic words into a meaningful sentence.

The Expert System (E.S.) branch is aimed at providing systems that can imitate human behaviour in approaching and solving problems that usually need experts for their resolution.

At the moment, all of the three above mentioned branches of AI are moving out of the limited area of research into the very large and fruitful area of industrial and business applications.

Nevertheless, the most valid results and the most favourable forecasts must be recognized as being in the field of Expert Systems.

This field corresponds to 30-35 % of the current AI market. The market share should rise in the near future .

Expert Systems have been developed to aid in solving problems relative to very varied fields.

Examples of the developments are : in the medical field, the world famous MYCIN by Stanford University, in the computer area the X.CON by Digital, in service and manufacturing systems areas the ACE by AT&T, and so on.

One of the most recent and exciting areas of the application of the E.S. approach is in the area of Computer Assisted Instruction (CAI) and Computer Based Training (CBT).

The Expert System used in those areas, along with the using of multi- media learning stations, allow the authors to design and develop Intelligent Computer Assisted Instruction (ICAI) coursewares.

While designing our E.S. model, we tried to profit from the approach for this new opportunity (ICAI) offered by E.S., as well as from the traditional advantages offered by E.S. in managing production and service systems.

Many papers have been written in the AI and in the CBE areas.
/1/ and /2/ refer to basic papers or book references dealing with the Expert Systems field.

2) KNOWLEDGE BASED EXPERT SYSTEMS

A Knowledge Based Expert System (KBES) is a form of decision- support system that has some of the features associated with human intelligence.

A Knowlegable Application (KA) is a computer program that performs decision- support functions in a way that exhibits some of the properties associated with human intelligence.

Actually, the property that distinguishes a KA is the "automatic reasoning" capability .

A KBES basically consists of two different parts :

- Knowledge Base (KB)
- Inference Engine (IE)

An activity cannot be intelligent without a Knowledge Base.
Therefore, a KBES has to first be provided with a Knowlege Base.
A Knowlege Base must not be confused with a Data (or Information) Base.
A book that trains people to assemble a computer is an Information Base (a set of texts and figures).
People who have read the book and learned the computer assembly techniques have got a Knowledge Base.

A Knowledge Base consists of a set of :

- facts concerned with objects ,
- definitions,
- formal rules that describe relationships,
- control information.

This set constitutes the basis for developing the heuristic reasoning that the human expert uses when he approaches a problem.

One of the most important aspects of KB is the representation of the human reasoning process in a way that is compatible with and understandable by the machine.

"Knowledge Engineering" is the science that enables the achievement of machine representation of human reasoning.

The Inference Engine is the generalized reasoning model and the dialogue manager.

It contains the :

- strategies to approach and solve a problem,
- ways to acquire the knowledge,
- interfaces with the external environment,
- procedures to provide explanations for the reasoning process that the E.S. is running.

Each Knowledge Base refers to a specific domain, the "Knowledge Domain" (K.B.).

The principal difference between a Knowledge Base and a traditional data structure is that the first one includes information on the facts as well as on the existing relationships amongst them.

The KBES approach utilises a set of programs which includes the relationships among the data and is external to the Data Base which contains only information, whereas the KBES approach provides that the Knowledge Base include both the set of facts and the set of rules.

The Inference Engine is external to the Knowledge Base.

Fig. 1 explains the two different schemes.

The facts are the basic elements that describe the problem that one is going to approach. Each fact may be supplied to the KBES either as an input or as a partial conclusion from the E.S. reaches.

The rules are conditional statements expressed in a formal but human-like language.

Each rule is constituted by two parts. The first one provides the recognition of a situation. The second part provides the actions that have to be undertaken on the basis of the conclusions reached at that point in time when the situation arises.

The Inference Engine analyzes the facts, administers the rules, and carries out the actions.

The Inference Engine is in charge of performing the reasoning process.

The reasoning process may be performed in two different ways :

- event driven (forward chaining) style,
- goal driven (backward chaining style) style.

In the first case, a goal is pursued starting from a set of facts. Operating in this way, the events drive the system toward the goal.

A "forward chain" of IF-THEN statements drives the Expert System to the searched for goal.

In the second case, the system starts from a conclusion and looks for rules whose actions find a solution to the pre-defined goal.

This reasoning style is known as "backward chaining". The chain of reasoning proceeds backwards through a series of THEN-IF statements.

The style is called "goal-driven" because the process is driven towards it's conclusion by the existence of an initial goal.

Many times, the E.S. inference engine will run both forward and backward chainings.

Problem diagnosis models often combine the two styles of reasoning.

Forward reasoning is used to generate possible problem solutions from the initial data.

Backward reasoning is then used to explore each possibility to collect supporting data during the process and to find out which is the most likely best solution of the problem.

2.1) Benefits from the use of KBES

A Knowledge Based Expert System approach is well suited to solve problems that are characterized by the following properties.

A) There are many different combinations of input data to be evaluated.

B) The conclusions that can be reached vary greatly.

C) The input data set is incomplete, not all the variables are deterministic and the sequence of input can vary randomly.

D) It is difficult or impossible to define precise relationships among the input data combinations and the conclusions to be reached. These re lationships are more easily defined in terms of individual rules each of which draws it's own sub- conclusion from a small subset of the input data.

E) It is difficult or impossible to include in the Knowledge Base all the facts and the rules involved in it's initial design. The KBES approach allows one to insert into the Knowledge Base new facts and rules as they are collected by the expert.

F) It is necessary to use a heuristic decision process. This means that we have to be satisfied with the reaching of a solution that is not necessarily the optimum solution, but is the best solution which can be found on the basis of the current knowledge.

In spite of three above mentioned benefits, the use of an Expert System reveals some limitations.

First of all, the benefits are almost always concerned with a long range time horizon; so that it is necessary to deal with very long Pay-Back periods for capital investments in the E.S. area.

Furthermore, an E.S. model becomes quickly obsolete because of the continuous and rapid changes in the technical environment.

The second element of difficulty is the presence of a diffused culture in the ES and AI fields.

Many experts are usually available in every scientific area, but the ES approach has only a small number of applications.

The development of an Expert System model needs a highly qualified working team characterized by a diversified but integrated knowledge. Unfortunately, experienced knowledge engineers are a scarce resource.

Last but not least, a prototype model of an Expert System is relatively easy to achieve , but the transformation of a prototype E.S. model into an applicative E.S. model is a hard task to perform.

2.2) Application methodologies and development tools

The KBES approach gives rise to a new kind of science: the science of "Knowledge Engineering".

The professionals in this field should be able to understand a problem and translate it into a KBES compatible form.

The translation process breaks down into the following steps :

1) Analysis of the original problem and it's decomposition into sub-problems.

2) Design of a KBES scheme.

3) Characterizing problem solutions in terms of an E.S. model.

4) Definitions of the facts and of the rules.

5) Selection of the most appropriate style of reasoning.

6) Design of the interfaces between the Expert System model and the End User.

This work methodology is similar to that which one uses to approach problems by "traditional" software applications.

Once the application has been developed in KBES terms, a prototype model should be built.

This prototype has to be documented, modified and improved by the working-team to obtain the final E.S. model application.

There are essentially two ways of developing applications in KBES terms : it may be possible to use :

- specifically designed knowledge engineering tools,
- general-purpose programming languages.

These special tools are also known as "Expert System Shells", because they provide the user with a lot of facilities : first of all, they do not require that the user be an expert in programming. He has to only be an expert in the problem area.

General-purpose programming languages (LISP, PROLOG, PASCAL, C, etc.) are more difficult to use than a shell, but these programming languages offer the potential for better functions and performance.

The hardware environment for a KBES model may be either a main-frame, a mini-computer, or a P.C.. The latter are currently so powerful that they can easily compete with the higher level computers.

3) COMPUTER BASED TRAINING

Teaching methodologies based on programmed instruction and the intensive use of multi-media teaching aids, known as Computer Based Education (CBE) of Computer Based Training (CBT), are becoming universally known for their utility in teaching as well as in the professional training field.

We have had the chance to develop, in collaboration with our Department's researchers, or with the help of outside software houses, a series of educational softwares (coursewares). These deal with many different sectors : schools, universities, service companies, banks, manufacturing companies, etc. /3/.

All the applications in the above mentioned sectors have profitted by the multi-media CBE approach. It has been proven that the learner retains up to 70% of what he studies in the case in which ;multi-media techniques are utilised in the building of the course.

Multi-media coursewares are specifically useful in training people who work in maintenance or manufacturing activities.

In these cases, the opportunities (obtaining information, simulating a process, seeing "live" images) offered by a multi-media teaching approach make it the best teaching approach conceivable at the moment.

With maintenance problems, seeing an image of the product (or the assembly part) we are dealing with is no less important than the gathering of all the other information concerning it.

The standard hardware configuration of a "Learning Station" for training purposes in the maintenance sector is basically constituted by a PC unit and a video display unit (videotape, videodisk , or CD-ROM), controlled by the computer.

This hardware configuration allows one to integrate the text's "video-pages " and the digitalized graphics, genefated and visualized on the personal computer's video screen with images captured live by means of a camera and visualized on an additional T.V. monitor.

An interface card and software permit the personal computer to "control" the activities of the video-tape; consequently the search and the visualization of the sequence of images chosen by the courseware's Author are completely controlled by the P.C. belonging to the work station.

The use of a video-tape instead of a video disk as an image support unit is of course cheaper and easier .

The use of a video disk unit may be convenient when one faces a problem in which the subject that the images refer to does not change it's configuration and it's components through time.

That is not the case of a maintenance problem. The bill of material and / or the maintenance procedures for each procedures for each product or assembly part vary very frequently and extensively.

The corresponding modifications of the images recorded on a video-disk support median is more expensive and more complex than is the changing of the images recorded on a video-tape support system.

On the basis of our experiences, we can also say that the handicap of the long search times of a video tape unit (as compared with the search times of a video disk unit) is not really a reason which should discourage the use of the video tape.

Usually, the search time does not exceed 5% of the watching time of the stream of images.

The software tools utilized for developing coursewares are the :

- authoring languages,

- authoring shells (authoring systems).

Authoring languages (PILOT,SEF.PC, etc.) are programmes specifically designed to develop educational softwares.

They are very powerful and allow the authors to achieve very exciting and well prepared coursewares . On the other hand, they are difficult to use; the courseware's authors have to be experts in the problem area, as well as having expert knowledge of programming techniques.

The authoring shells provide the authors with tools that are extremely easy to use and which do not require an extensive programming background.

Many excellent authoring systems or shells are available in the software market.

However, for our CBE applications, we preferred to design and develop our own authoring shell.

Masturzi designed the SEF.ASSISTANT authoring shell, and Technova achieved it.

SEF.ASSISTANT is an authoring shell that self-develops coursewares very easily and quickly. The " final product " of the SEF.ASSISTANT is a courseware written in an authoring language which is powerful, well supported, and widely diffused.

This is so that a lot of the most enhanced teaching aid units (i.e. video disks, video-tapes, CD-ROM, scanners, laser printers, cameras, etc.) may be "called" by the author inside his teaching software.

/4/ explains in detail the objectives and the features of the SEF.ASSISTANT authoring shell.

The coursewares architecture we adopted for the CBT part of our model is the "Integrated Teaching Unit " (ITU) architecture proposed by Masturzi in /5/.

That courseware architecture is characterized by the highest level of integration present among three basic components:

1) text reference book,

2) CBT courseware,

3) Applicative softwares

As will be explained in depth shortly, the ITU architecture has been achieved in our model by means of the integration of the :

1) maintenance reference manuals,

2) CBT multi-media courseware,

3) Knowledge Based Expert System Software.

4) THE EX.MAIN MODEL

The previous overview on the KBES and CBT topics reveals a new and very exciting environment which one is tempted to explore.

If a KBES model was so powerful in the maintenance field and if a CBT multi-media teaching model might be usefully employed to train people operating in production systems, why should we not try to put together the two models in order to achieve a "global" model , characterized by the advantages of both of the two single models ?

EX.MAIN is an example of a global model in the maintenance field that we have designed and developed keeping in mind both the KBES approach and the CBT approach.

While designing EX.MAIN, our basic objectives were to provide the maintenance staff with :

1) an aid to the collecting of the proper and sufficient data in order to quickly and exactly identify the components of a system involved in the failure.

2) an automatic procedure able to find the presumable origins of a failure and to identify the components of a system involved in the failure.

3) a list of operations that should be performed to repair the failure .

4) a training course which can supply the necessary know-how in the case in which the maintenance operators need it.

4.1) Hardware and software configuration

The EX.MAIN model has been structured as indicated in Fig.2.

From the hardware point of view, EX.MAIN consists of an IBM Personal Computer and a colour graphic video screen. The "image base" support is a professional VHS video-tape player connected with a T.V. monitor. A plug-in card allows the PC to drive the video-tape.

The basic software involved in the KBES part of the model is a shell (EXSYS) able to manage a set of up to 5000 rules. The inference engine runs both the forward and the backward chaining. A "probabilistic weight"" can be associated to each fact and therefore to each conclusion.

The ES shell allows the author to "export" and "import" data to and from other softwares outside of the KBES enviornment.

The softwares may be either standard (i.e. Lotus 1-2-3, Base III, etc.) or customized on the basis of the end user's requirements.

The basic softwares involved in the CBT part of the EX.MAIN model are the authoring shell SEF.ASSISTANT developed by Technova and a set of micro-instructions able to drive the image's base equipment.

SEF.ASSISTANT allows the author to achieve a "screen base" including all kinds of video-pages (texts, graphics, questions, suggestions, etc.) used inside the courseware. The single video-pages are afterwards searched , selected , put in the right sequence and then linked to obtain the "learning trail" that the author expects.

The SEF.ASSISTANT shell allows the integration of the CBT softwares with external softwares or Data Bases. The software may be standard, as well as customized.

Digital graphic pages can be captured (for example, scanners) or created (for example , by a graphic tablet, by a mouse, or by software) and then inserted into the courseware video-pages stream.

When the author wants to show "live " images he inserts specific video-tape driving instructions into his learning trail. The PC searches the sub-set of live images the author expected to see and runs the video tape equipment. the images are displayed on the TV monitor connected with the video tape.

4.2) Model description

EX.MAIN has been conceived to provide a global model in the maintenance field characterized by both :

- operative features.
- training features.

The operative features are included in the KBES part.
The Knowledge Base Domain is concerned with the air-braking system of an electric train (locomotive and carriages).

When a failure (or a problem) occurs an alarm signal (visual and acoustic) actuates.
The train operators then know that some irregular conditions are in existence.
When the train arrives at the closest station, the train operators and the maintenance staff check the braking system and consider whether or not to continue the trip.

The KBES model provides the staff with an aid for decision making.
First of all, it reminds them of which components have to be checked.
It asks questions about the symptoms and the nature of the failure.
Starting from the conclusion about the kind of failure that has occurred, the ES model chains backwards trying to identify the set of causes that best fit the final event.
The symptoms of each braking systems component failure previously introduced in the Knowledge Base are compared with the symptoms of the failure noticed by the staff.
The Expert System provides the staff with the best conclusion it can reach on the basis of the available input data.
The conclusion is displayed in the form of a mix of alternatives, each one weighted by means of a probabilistic coefficient.
Once the ES model has completed the problem diagnosis, the appropriate maintenance procedure can be printed.

The KBES model gives to EX.MAIN functions which characterize it as an "operative" expert procedure.

But training features also characterize EX.MAIN as a training procedure.

In fact, the CBT model also provides a training course if the staff lacks know-how for some maintenance operations.

The CBT model, based on the multi-media concepts, gives to the staff the required information by means of a text and graphic video-pages as well as by means of live images of the braking - system components displayed on a TV monitor.

The maintenance procedures are also illustrated by means of a video-tape recording.

Sketches and tables directly abstracted from the maintenance manuals supplied by the braking system manufacturer are also inserted in the CBT courseware with the aid of a scanner.

The way in which an EX.MAIN model runs is explained in Fig.3.

5) THE WORKING TEAM

The EX.MAIN model has been conceived and developed within the framework of a cooperative agreement existing between the College of Manufacturing of Cranfield Institute of Technology (U.K.) and the Depatment of Production Engineering of Naples University (I).

The two University staffs have been in cooperation since 1985, achieving research and educational programmes in the manufacturing area.

A trans-national course on "Production Management" designed and developed by the two above mentioned Universities has been granted by the CEE within the ERASMUS program.

The EX.MAIN research project was jointly developed by members of the two Universities and by members of two Italian companies.

The first one is "Ferrovia Circumvesuviana", the largest railway company in Italy after the National railway company (Ferrovia dello Stato: F.S.).The Circumvesuviana railway links many towns located in an area just around Naples; and that area is large and very crowded.

The railway company moves about 300,000 people per day, who generally commute from their towns to Naples and viceversa.

The other partner in the project was Technova, a private company which operates in the area of the high technology applications.

The Technova staff designed and produced many CBT coursewares and developed significant software tools (authoring shell, authoring systems, etc.) in the Computer Based Educational field.

To develop the project, a working team was constituted . It included experts in:

- production systems problems,
- artificial intelligence and expert systems,
- educational and training problems.

Once the subject of the research has been defined, (the maintenance of the air-braking system of a train) the maintenance manager of the Circumvesuviana and two members of his staff were included in the working team. They supplied the information required to achieve the Knowledge Domain concerned with the problem.

The two University members included in the working team provided the project management, the technological research, the systematic approach to the problem and the training consultancy.

The manager of the "Systems and Organization Department" of the Vesuviana and some members of his staff were also involved in the working team.

They were in charge of the systems analysis and of the development of the special software.

The members of Technova included in the working team were in charge of the designing and developing of the "course script" as well as of the courseware manufacturing.

All the activities concerned with the CBT model were performed by the Technova staff.

The design and the production of the KBES model were jointly performed by the members of Circumvesuviana and of Technova.

Fig. 4 summarizes the working team mix.

While recruiting the working team's members, we faced problems we believe to be common to all the projects which concern a new area.

Not many people are experienced in the application of Expert Systems and of Computer Based Training.

That is because companies have not yet achieved enough experience in both these fields.

On the other hand, Universities do not train students in AI applications and in CBE methodologies.

Experts in this growing science will be available in a sufficient number if and only if the Universities prepare students , and the companies convince themselves that the experts cannot be recruited from the outside, but they should be chosen and trained from within.

6) CONCLUSIONS

The EX.MAIN project is an attempt to achieve a global model which gathers the features and the advantages that characterize the KBES and the CBT models.

The General Electric research and development center has developed the DELTA model to aid the maintenance staff in solving problems concerning failures of diesel electric locomotives.

DELTA is a KBES model which consists of 530 rules in total. About 300 rules deal with troubleshooting activities, and the other rules deal with assistance procedures.

The DELTA model has only operative objectives; it has no training objectives.

The EX.MAIN model does not refer to the maintenance of a whole locomotive , but it refers only to the air-braking system. It is focused on one problem, perhaps the most important for the transportation vehicles.

EX.MAIN Knowledge Base includes about 200 rules, all concerned with the specific above mentioned problem.

The CBT part of EX.MAIN consists of a set of more than 250 video-pages and 5 films (recorded on a VHS video cassette) that constitute the training courseware.

The experience we have obtained through achieving the EX.MAIN model is undoubtedly useful.

The project development allows one to collect different know-how and knowledge, to research and document working methodologies and working tools, and to have useful experiences in both the KBES and CBT fields.

We hope the achieved results allow the birth of a new project characterized by operative and not only experimental purposes.

The developing costs of a project like EX.MAIN are certainly high, but the potential benefits are even greater.

The costs regard the present, the benefits will come in the future; unfortunately, not many companies can afford this long-range pay-back.

The high capital investment required by a KBES and a CBT model may be justified by the benefits that the Maintenance Department and the Education Department of a company can both enjoy from the use of this global model.

In fact, the KBES model may be used alone as an operative maintenance aid.

On the other hand, the CBT model may be efficiently used to train people inside ordinary training programmes.

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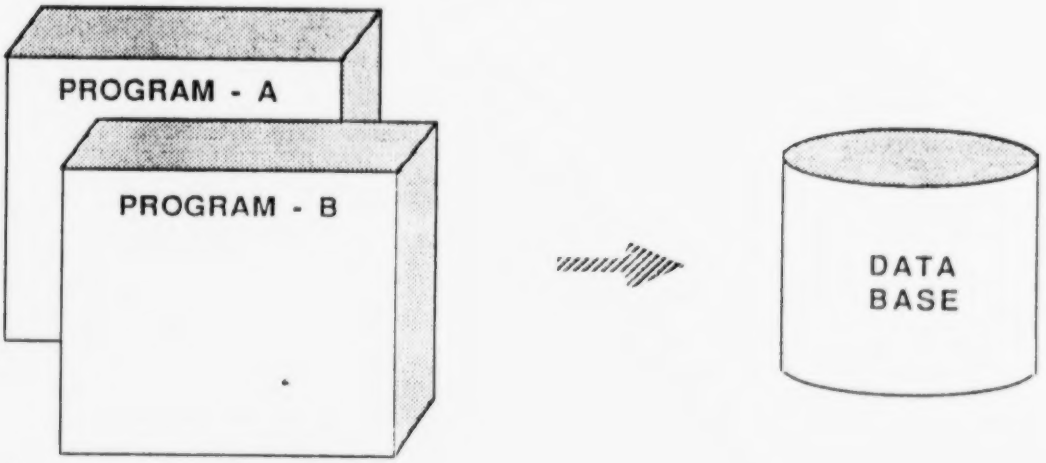
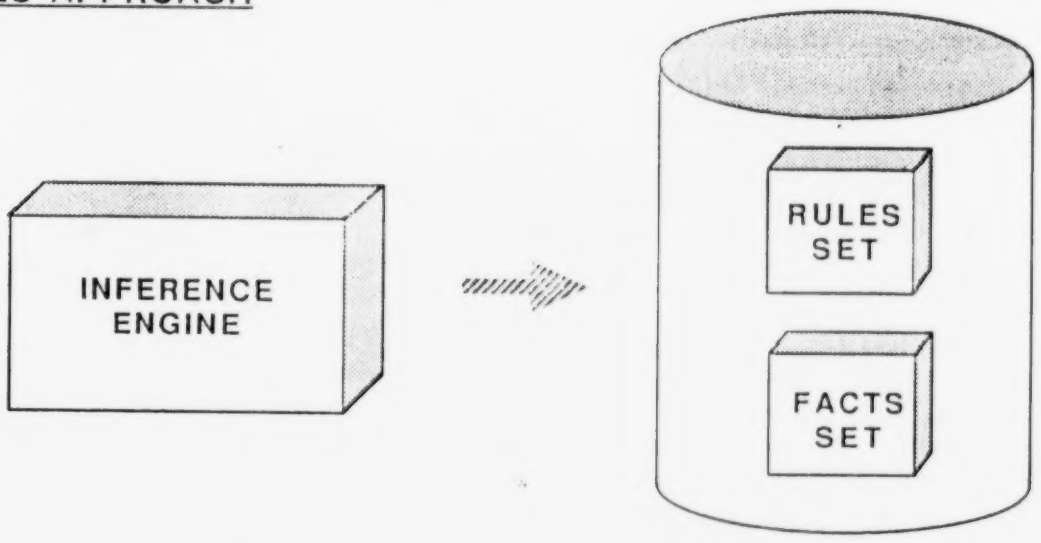
TRADITIONAL APPROACH



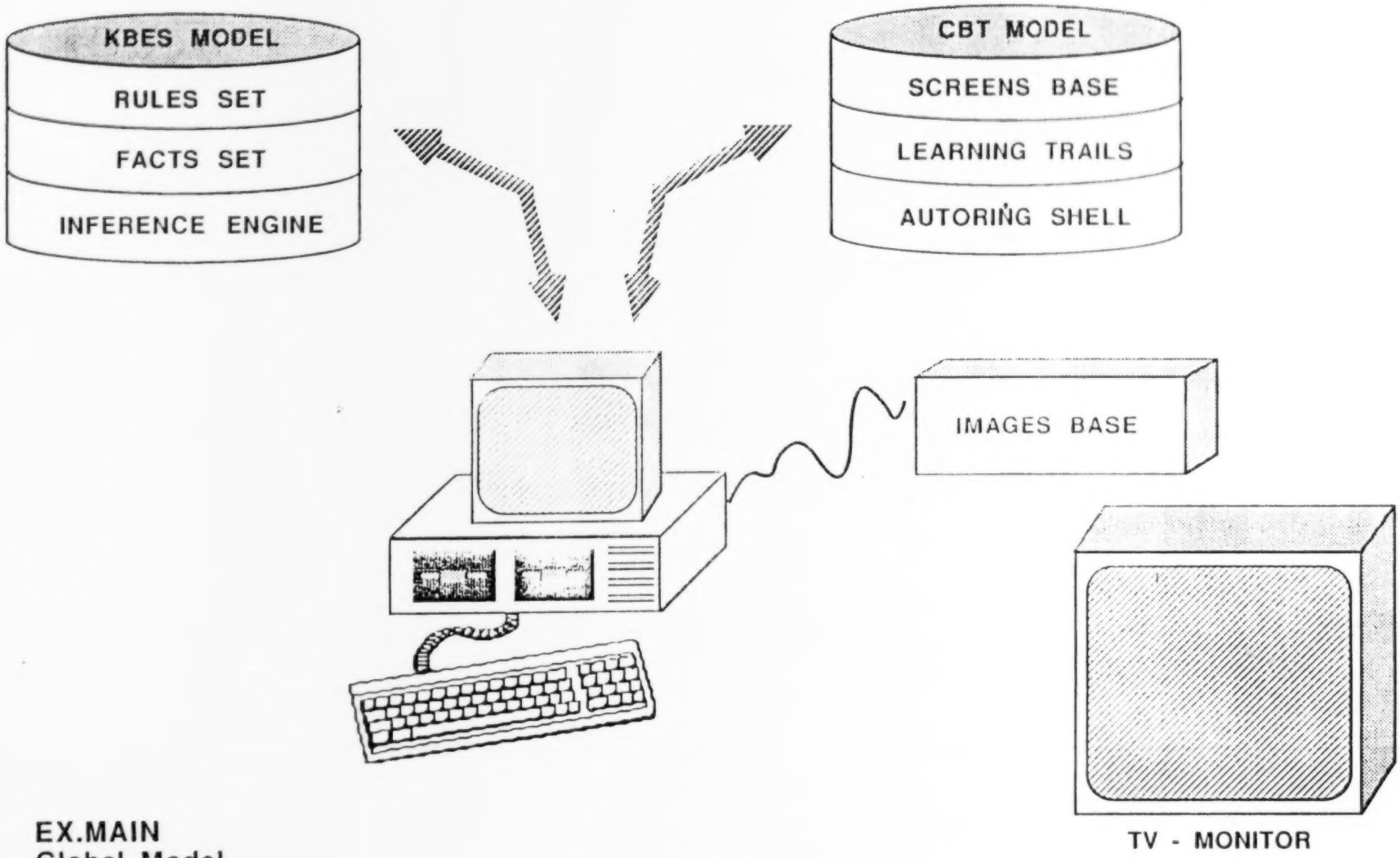
PROGRAMS SET

KBES APPROACH



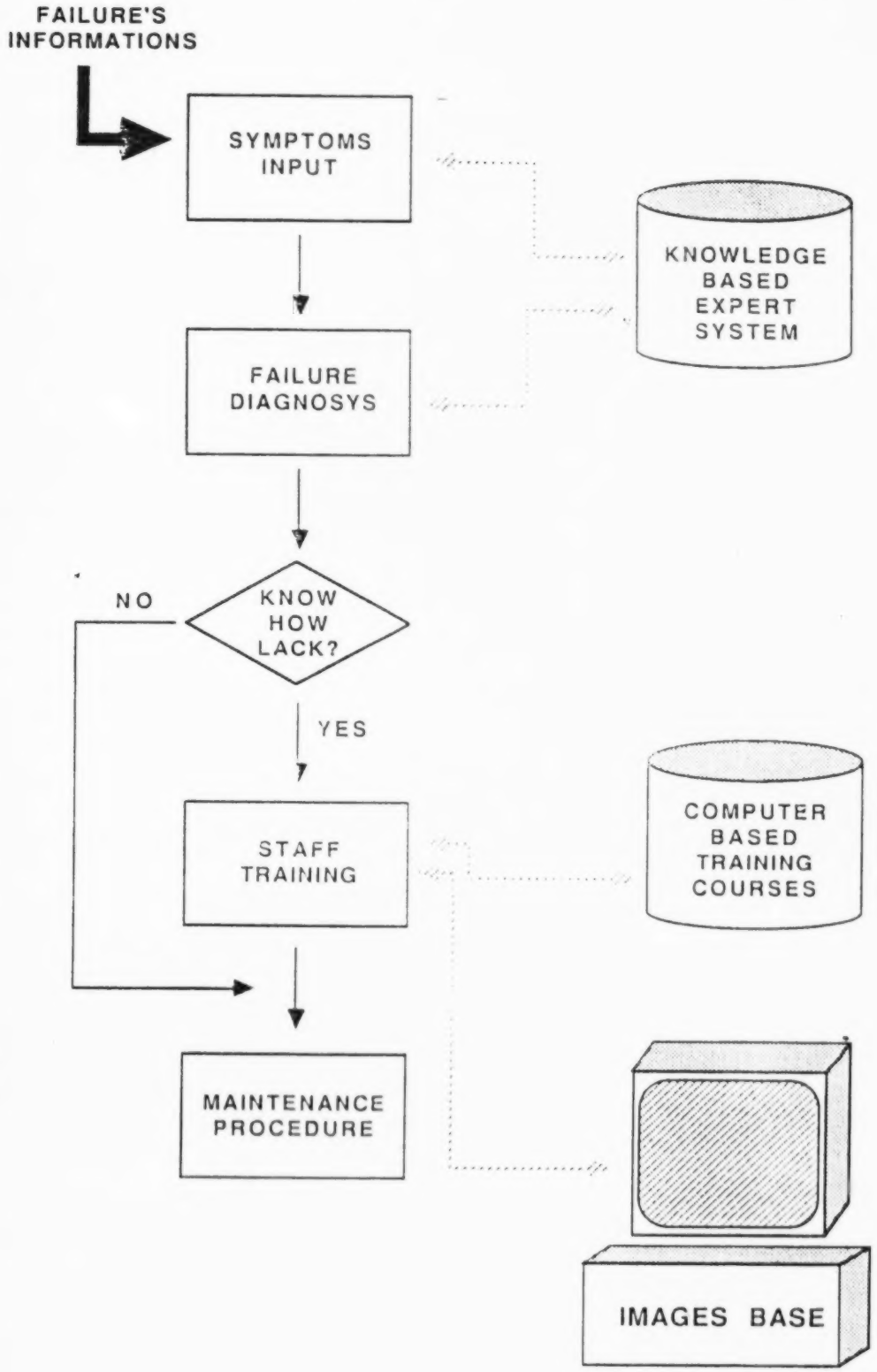
KNOWLEDGE BASE

(Fig. 1)



EX.MAIN
Global Model

(Fig. 2)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(Fig. 3)

WORKING TEAM

(Fig. 4)